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FIG. 1.—A FIELD OF CHILE PEPPER, SHOWING INFECTED AREAS WHERE THE PLANTS HAVE BEEN KILLED BY FUSARIUM ANNUUM.

FUSARIUM WILT OF CHILE PEPPER

BY LEON H. LEONIAN

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New Mexico Agricultural Experiment Station

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Fusarium Wilt of Chile Pepper

A wilt of chile pepper was observed for the first time on the farm of the New Mexico Experiment Station in 1908. Three years later when general attention was called to this disease, it was so prevalent all along the Rio Grande Valley "as seriously to impair the output of chile pepper for the year." The farmers who had been growing the crop became very desirous of finding a remedy for the trouble; turning naturally to the Experiment Station for assistance. H. S. Hammond, then botanist for the Station, started the investigation of this disease as an Adams project and continued it for three years. After him Mann, Werkenthin, and finally the writer successively took charge of the problem. While this paper gives the results of the investigations extending from 1911 to 1919, the work done during 1918-19 forms its principal part.

THE HOST

The word *chile* is the Spanish name used for red peppers (Capsicum annuum). This name, however, has been generally used to distinguish the "hot" type of red peppers from such mild varieties as Bull-nose, Chinese Giant, Ruby King, etc.

The chile pepper is used extensively as an article of diet by the Spanish speaking population of the Southwestern part of the United States and in Mexico, and its use is gradually becoming more general among the Anglo-Americans. It is eaten both in the green and in the ripe state. Green peppers are canned in large quantities, while the ripe pods are dried and stored for future use.

Chile pepper is a good producer. As high as 20,290* pounds of green pods per acre have been produced on the Station farm. Twenty dollars a ton is an average market price for this product. The College variety No. 9 has yielded as much as 2,676† pounds of dry chile to the acre. Dry peppers seldom sell for less than ten cents a pound. This means large profits, and the farmers have been quick to realize it. Ever since the appearance of the chile blight, however, the growing of this crop has been regarded a venturesome occupation.

*N. M. Sta. Bul. No. 67, P. 26.
†N. M. Press Bul. No. 289.

THE DISEASE

The Name.—This disease is known by the name of "chile blight," "wilt," and "black leg of chile." The name "chile blight" is most commonly used. *Fusarium wilt of chile pepper,* however, is proposed as a more appropriate name.

Origin and distribution.—New Mexico seems to be the only state, according to records, where this disease is present and serious enough to cause trouble. A circular letter was sent to every Experiment Station in the southern, southwestern, and western states where peppers grow successfully, asking information about the diseases of peppers, especially about wilts. Prof. Smith reported that a wilt is quite a common occurrence on winter grown peppers in California, and although he had isolated a Fusarium species from the infected material, he had not attempted to reproduce the fungus from artificial inoculations. Prof. Ness, Horticulturist of the Texas Station, has noticed occasionally, some sort of blight on chile peppers; Dr. Taubenhaus thinks this blight is probably due to Sclerotium rolfsii, since this fungus is very prevalent in Texas, where it causes a serious blight of tomatoes. Prof. J. L. Hewitt stated that his attention had been called to a disease of ordinary sweet peppers in Arkansas. He believed, however, that the trouble was of bacterial origin, although he did not attempt to determine the real nature of the causal organism.

Previous work.—H. S. Hammond was the first investigator to take up the problem of "chile blight," in 1911. He believed that Bacterium solanacearum was the causal organism and that the trouble was confined to parts of plants above the ground. During the year 1914-15 the investigation was continued by J. M. Mann, who came to the conclusion that the disease was not of bacterial origin, but that it was due to some fungus. He did not, however, prove this definitely, nor did he attempt to identify the fungus. It remained for F. C. Werkenthin to isolate the causal organism, a Fusarium species. Some of his inoculations, both in the greenhouse and in the field, gave positive results. He grew seedlings under sterile conditions, and when he inoculated them with this Fusarium species, the greater majority of the seedlings wilted and died. He did not, however, finish the identification of the fungus, nor did he work out its physiology. The writer took charge of the investigations in the fall of 1918.

Economic importance.—Previous to 1908 this disease was unknown. That year Garcia (1) stated that "There were no diseases troubling the chile." In 1911 there was an outbreak of the disease, and at present most of the chile growing sections of the

State have more or less of it. The severity of the infection varies in different localities and causes a loss of ten to ninety per cent of the entire crop. This disease is the chief factor which limits a profitable production of chile peppers. Nematodes and an Alternaria fruit rot and stem blight are of secondary importance.

Symptoms.—A rapid wilting of the leaves and drooping of the younger shoots, followed by a general browning and drying of the foliage, constitute the characteristic signs of the disease. Wilting first affects the lower leaves, which curl perpendicularly to their middle vein and droop; later the upper leaves are similarly affected. This process generally takes place in a very short time. In one instance the writer observed a plant which appeared normal at 9 a. m., but was completely wilted two hours later. The stems, on account of their woody nature, remain erect after the drooping and the consequent falling off of the the majority of the leaves; but the young shoots, and the tender, growing parts droop and soon dry.

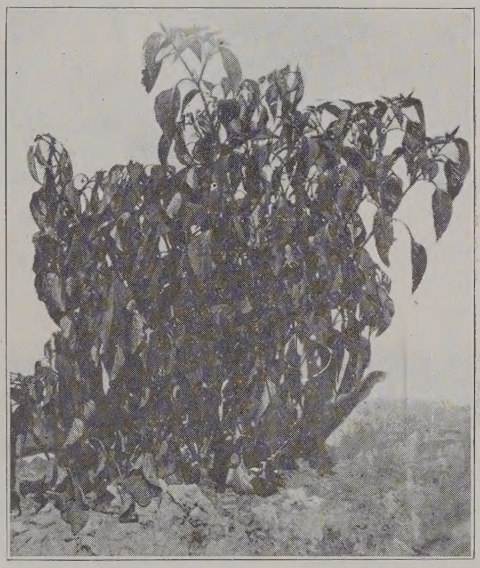

FIG. 2.—A CHILE PEPPER PLANT JUST BEGINNING TO WILT.

The roots, the underground stem, and often the lower part of the stem above the ground may be invaded by the pathogen. Dark brown and sunken lesions may appear on the base of the aerial stem of the affected plants, and by a gradual circling movement they girdle the stem. The bark becomes dry and brown, and the wood beneath is darkened. This darkening may be confined to the outermost layers alone, or it may involve all the tissues, the pith included.

When a newly wilted plant is dug and examined, a part of, or

more commonly the whole underground stem, as well as a portion of the roots, will appear browned or blackened. The affected bark

FIG. 3.—HEALTHY PLANT ON THE LEFT; WILTED ON THE RIGHT.

of the underground stem, especially in wet soils, is reduced to a dark mass of broken down tissues which easily rub off between the fingers, exposing a smoke-colored wood. When a wilted plant is

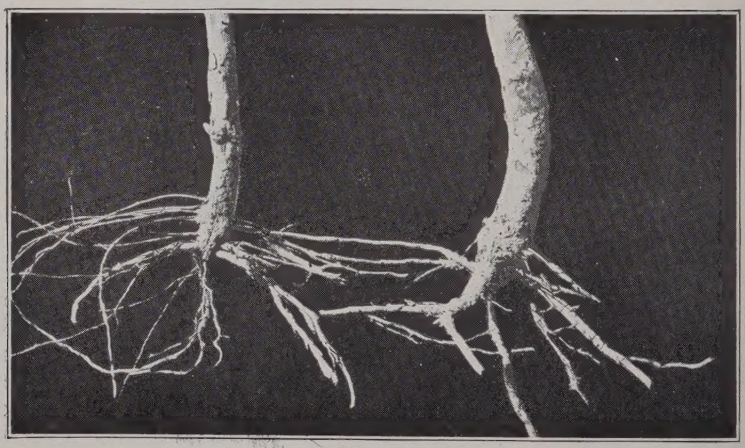

FIG. 4.—THE LOWER PARTS OF THE TWO DISEASED PLANTS, SHOWING THE INFECTED UNDERGROUND STEM FROM WHICH THE BARK IS PEELING OFF.

pulled out of the ground the cork cambium peels off from the badly infected roots and remains in the soil. The diseased roots are dark brown, at first brittle, then soft and water soaked; whereas the healthy roots are creamy in color, and strong and rigid in structure. The infection may be confined to a few roots alone, or it may alternate with the healthy parts on the same root. Often, immediately after the wilting of the plant, most of the roots may be found unaffected, while the base or any of the regions of the underground stem may be browned or blackened as the result of the activities of the fungus. Less frequently the majority of the roots may be diseased, while only the basal portion or the stool of the underground stem may be affected. This is generally the case when the young plants are not set too deep and the roots are nearer the surface layers of the soil where the fungus seems to thrive best. The underground stem of diseased plants, especially in wet soils, may become covered with white or bluish-green sporodochia of the fungus four or five days after the wilting of the plants. No sporodochia have been observed on the stems above the ground.

Effect.—The general effect of the disease upon the crop is quite striking. Groups of wilting or dead plants, some with a few of their shriveled, dry, brown leaves still clinging to them, are very conspicuous in a field of green plants. The infected areas form various sized patches which gradually enlarge as the season progresses. If the plants are attacked early in the season, no fruit is formed and the plant is a total loss to the grower. If the disease does not manifest itself until late summer, the pods can be harvested and sold as green chile pepper. If left on the vines, they soon shrivel and fall off. In case the plants are not diseased until late in the season, the green pods will mature after the death of the plant, but will lack the fleshiness of the pods matured on healthy plants.

ETIOLOGY

The writer's predecessor, F. C. Werkenthin, repeatedly isolated a Fusarium species from wilted peppers. A very large number of isolations made by the writer yielded the same organism. This fungus belongs to the section Martiella, and exhibits physiological and morphological characteristics not like those possessed by the other species of the section Martiella. The writer realizes the fact that many of the species of Fusaria in a given section have a very close and often confusing resemblance, and that some of their morphological properties are subject to rapid fluctuations, but since the other species of the section Martiella were found unable to

attack chile peppers even under the most favorable conditions, and since none of them yielded cultural and morphological characteristics identical with those of the chile wilt organism, the writer felt justified in classifying it as a new species. *F. annuum* is the name proposed for this fungus.

The following tables give the average sizes and the percentages of the spores of F. annuum as compared with the sizes and percentages of the spores of the other species in the section Martiella. The figures for F. eumartii are given by Carpenter (2), those for F. martii, F. solani, F. striatum, F. radicicola, and F. coeroleum have been taken from Sherbakoff's (3) Fusaria of potatoes.

Table I.—A comparison of the sizes of spores of F. annuum and those of the other species of the section Martiella.

	0-septate	1-sept.	2-sept.	3-sept.	4-sept.	5-sept.	6, 7, 8-septate
	Microns	Microns	Microns	Microns	Microns	Microns	Microns
F. annuum	11.2x4.4	17x5.5	25.2x5.2	39.2x6.1	46.3x6.5	50x6.5	Very rare, 46x6.5
F. martii	11x4	20x4.5	V'y rare	43.9x5.1	49.3x5.3	54.3x5.5	
F. solani	8.7x4	17x4.3	22.5x4.6	29.7x5.5	35.5x5.8	44.3x5.8	
F. striatum	10x3.4	20x3.9	24.5x4.2	34.7x4.6	43.7x4.7	50x4.8	
F. radicicola	8x3	15x4		34.2x4.7	43.9x5.1	43.9x5.1	
F. eumartii					54.4x5.6	63.7x5.8	69.7x6.3, 71.6x6.5

Table II.—A comparison of the Percentages of Spores of F. annuum and those of the other species of the section Martiella.

	0-sept.	1-sept.	2-sept.	3-sept.	4-sept.	5-sept.	6-, 7-, 8-sept.
	%	%	%	%	%	%	% %
F. annuum	25.3	20.2	3	30.1	10.3	12.1	Very rare
F. martii	Rare	1	Very rare	53	43	3	
F. solani	5	11	6	76.5	1.5	Rare	
F. striatum	12	19.5	5.5	60	3	Very rare	
F. radicicola	56	16	3	23	2	Very rare	
F. coeroleum	4	6	5	78	4.5	2	
F. eumartii				7	20	50	8 15

Steamed pepper stems, potato hard agar containing ten per cent glucose, and potato cylinders were the chief media used in culture work. Spores from these cultures, as well as from the sporodochia developed upon the underground stems of the plants which wilted in the field, were used in determining the sizes and the percentages of the different septate spores of F. annuum. It was found that 0-septate conidia predominated in the mycelium, often representing 95 per cent of all the spores. 3-septate, and often 4- and 5-septate spores on the other hand, especially under field conditions, formed the greatest majority of conidia in the sporodochia.

The most important physiological difference between F. annuum and the other species of the section Martiella is that the other species are not capable of attacking chile peppers. This was proved by a number of inoculations under controlled and sterile conditions. While the color reactions of F. annuum and those of the other species are quite different from one another, they cannot be considered

constant or reliable characteristics, as the slightest change in the medium brings about a rapid fluctuation.

F. annuum n. sp.—Microconidia are always present in large numbers, and are the first spores to appear in cultures. Macroconidia are mostly 3-septate, although 4- and 5-septate spores may, occasionally, be in the majority, especially under field conditions. Chlamydospores are mostly 0-septate and measure from 7 to 10.5 microns. They develop abundantly in the old cultures and may be both terminal and intercalary, borne singly, or in chains and clusters. Sclerotia form in large numbers, especially on whole, steamed potato tubers. They are generally flesh colored, darkening with age. The color reactions of this fungus vary according to the media; on potato plug they are bluish-green with the sporodochia showing a flesh or greenish tinge. A purplish brown color develops in steamed rice cultures, while on potato agar rich in glucose a salmon-colored reaction is followed by a dark purple.

Pathogenicity.—The fungus has been repeatedly isolated both from the roots and the stem lesions of wilted chile peppers. It develops very readily in cultures within three or four days. The constant association of the fungus and the host was demonstrated in hundreds of isolations made both by Werkenthin and the writer. Isolations were made by the writer throughout the year 1918-19. Badly decayed or newly attacked rootlets, roots, underground stems and infected aerial stems were used in all stages of development. Cultures were also made from the sporodochia formed on the underground stems. All of these isolations yielded the same organism.

The inoculation experiments were carried on both in the laboratory and in the field. Pot and water cultures were prepared and the plants were inoculated throughout the year. One-week-old seedlings, as well as young, and fully developed plants were used.

Chile pepper seeds were soaked over night in distilled water, then washed in 1-1,000 mercuric chloride solution for ten minutes, rinsed with distilled sterile water, and planted in Petri dishes containing a weak nutrient media (ammonium nitrate 1 g., dihydrogen potassium phosphate 0.5 g., magnesium sulphate 0.25 g., iron chloride, trace, cane sugar 5 g. agar agar 10 g., water 1,000 c. c.) As soon as the seeds germinated, the nutrient media in the dishes was inoculated with F. annuum. The growth of the fungus, which was quite sparse, was followed as it advanced towards the seedlings. The infection took place most readily at the tip of the primary root, which browned one day after coming into contact with the hyphae

of the fungus. Gradually this discoloration advanced, involving the secondary roots, the hypocotyl, and the primary leaves.

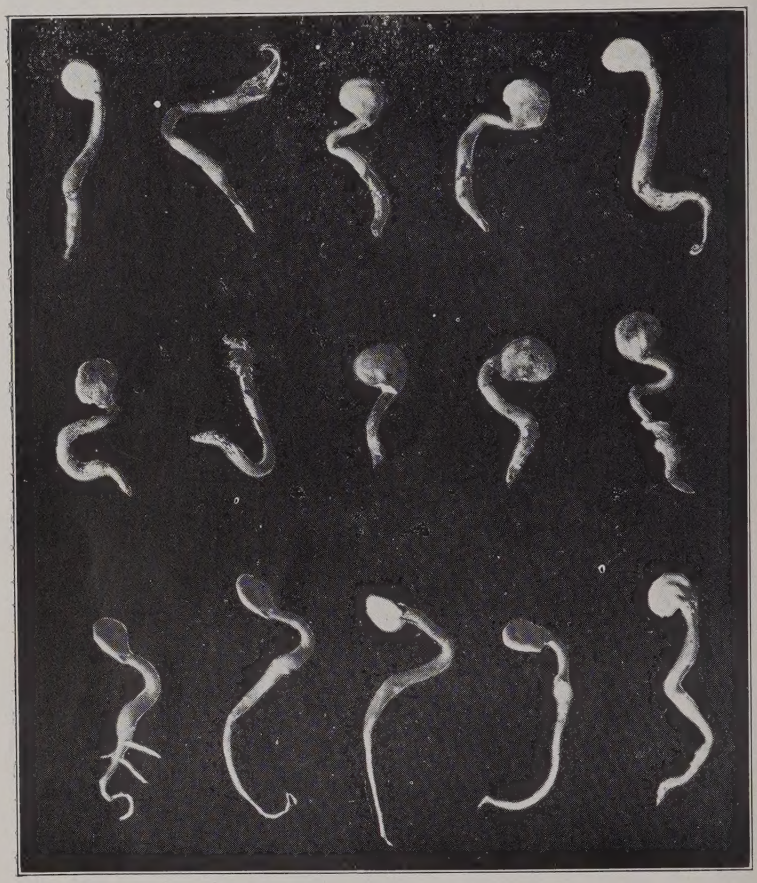

FIG. 5.—CHILE PEPPER SEEDLINGS. UPPER TWO ROWS INOCULATED, LOWER ROW CHECK.

The seedlings died 8 to 10 days after inoculation, at a temperature of about 27°C. The fungus was re-isolated from the hypocotyl lesions of the seedlings. All checks remained unaffected.

Seeds were planted in both autoclaved and untreated garden soils. As soon as the seedlings appeared, the soil was inoculated

with F. annuum by applying spore dilutions to each sample. The soil was kept constantly wet and at a temperature of about 27° C. After ten days most of the inoculated seedlings died, and a few days later the remaining seedlings wilted. All checks remained unaffected.

The soil used for larger plants was a rich sandy loam, sterilized in the autoclave.

Pfeffer's formula, as given below, was used for making water cultures:-

Calcium nitrate	4 g.
Potassium nitrate	1 g.
Magnesium sulphate	1 g.
Potassium acid phosphate	1 g.
Ferric chloride solution	trace
Distilled water	7 litres

The nutrient solution was placed in wide-mouthed, cotton-stoppered beakers of 500 c. c. capacity and sterilized. For the larger sized plants, beakers of 1,200 c. c. capacity were used. The chile pepper plants were carefully dug out of the soil, thoroughly washed (rejecting those which showed any trace of browning on their roots), kept in distilled water overnight, then placed in a 1-1,000 solution of mercuric chloride for five minutes, again washed with distilled, sterile water, and were planted in the pots, or transferred to the beakers containing the nutrient solution. The total number of these cultures was about one hundred. Every third pot or beaker was used as a check, and the rest were inoculated with F. annuum. Cultures of the fungus were thoroughly mixed with sterile water, and an equal amount of this mixture was applied to each pot or beaker. The temperature of the room varied from 25° to 30° C. Two weeks after the inoculation ninety per cent of the plants growing in the water cultures wilted and showed the characteristic lesions of Fusarium wilt. Sporodochia developed upon the stem above the surface of the solution four days after the wilting of the plants. F. annuum was re-isolated from the wilted plants. All checks remained unaffected.

Those of the potted plants which were kept at a temperature of 25° to 30° C. wilted from four to six weeks after the inoculation. The rest of the plants, which were kept at a temperature considerably below 25° C. (10° to 15° C.), did not wilt until the return of summer months. Eighty per cent of the pot inoculations gave positive results.

The first field inoculations were made on the 15th of May, 1919. The plants were then about eight inches high. Cultures of

F. annuum were washed and mixed with water; the dirt was removed from the base of the plants, and about 300 c. c. of the water containing the fungus spores and hyphae was applied to the soil; then the dirt was replaced. Inoculations were made successively during June, July and August. Two hundred plants were inoculated. All these plants were growing on the high and drier part of the field. No wilted plants were observed in this field until the first of August. Ninety-five per cent of the inoculated plants failed to show any infection This at first seemed very puzzling. A few days later it was noticed that the wilt was very prevalent in the lower part of the same plot and that about twenty-five per cent of the plants were affected. None of the plants in this part

FIG. 6—No. 1, CHECK; NOS. 2, 3, AND 4, INOCULATED.

of the field were inoculated and the land was occupied, prior to being planted to chile peppers, by old peach trees. The lower and wetter part of another plot, not more than twenty-five yards away, became infected still more heavily, and eighty-five per cent of the plants wilted, while the upper and drier part of the same field showed only two per cent infection. It was then believed that the lack of proper drainage and the very high moisture content characteristic of these low spots in the fields were closely related to the occurrence of the disease. A number of healthy plants were selected in the lower part of the plot which showed a twenty-five per cent infection,

and were inoculated with F. annuum. Sixty-five per cent of these plants wilted and died one month after the inoculation.

Some inoculation experiments were performed in the laboratory to see if the fungus was able to attack the parts of the plants above the ground. Spores were sprayed on both injured and uninjured leaves and stems of ten plants, which were then placed in a moist chamber and kept at a temperature of 30° C. With one exception, the plants gave negative results. In the case of this one plant the primary infection started from the stub of a broken branch and gradually worked its way into the main stem, and continued to spread until the stem was girdled and the plant died. After the upward movement of the infection in the stem ceased, a rapid downward movement took place. In a week's time the entire root system was affected.

Dissemination.—Soil is the primary source of inoculum, and anything that will carry the soil from one place to another will also be able to carry the fungus along. The responsible agents for the spread of this parasite are dust storms, irrigation waters and methods of irrigation, the direct growth of the fungus hyphae in the soil, the remains of diseased plants, and cold-frame infection of the seedlings.

*Dust storms**—Dust storms are common in New Mexico during the months of February, March and April. The wind at times attains a velocity of fifty miles or more an hour. The air becomes full of fine dust and sand which, lashed by strong winds, rush ahead rapidly and cover long distances before settling down. Most of the plowing and harrowing is done during these stormy months. The loose dirt and any pathogenic organisms which it might contain are blown from one place to another. Bacteria, spores, hyphae, clinging to dirt particles or to bits of organic matter, may be carried from one farm to another, many miles away. This perhaps explains why even a virgin land is often found to be infested with pathogenic oganisms. The value of crop rotation is thus rendered less reliable, and the dissemination of pathogenic organisms more rapid and serious.

The spores of F. annuum can withstand desiccation for hours, and thus are able to travel in dust storms for long distances without losing their vitality. Some experiments were performed to test this. Spores were transferred to a drop of sterile water on a series of slides, and were allowed to dry at ordinary room tem-

*This bulletin was ready for the printer when an artice by H. G. MacMillan entitled "Wind and the Distribution of Pathogenic Soil Organisms" appeared in Phytopathology (Vol. 9, No. 10, pp. 471-473, Pl. XXXVI).

peratures.

The slides were divided into three groups; the first and the second groups were kept outdoors in the shade and in the sunlight, respectively, while the third group of slides was placed in an incubator. The temperature in the shade varied from 15° to 20° C.; in the sunlight it was 28° to 32° C.; while in the incubator it remained about 30°. Slides from each group were taken into the laboratory at regular intervals; a drop of sterile water was placed upon the film of the spores, and the slides were kept in a moist chamber. At the end of 24 hours they were examined under the microscope for germination. It was found that the spores kept their vitality for four hours in the direct sunlight, for forty-eight hours in the shade, and for six hours in the incubator.

A number of sterile platinum wires were dipped into the sporodochia of F. annuum, then capped with sterile paper and kept in the incubator at a temperature of 30° C. The vitality of these spores was tested every other day by transferring them to nutrient agar. The spores kept their vitality for eighteen days.

In order to determine the amount of protection afforded by the soil against desiccation, several samples of a sandy loam soil were chosen, placed in covered glass dishes and sterilized in the autoclave. Spores from the sporodochia of F. annuum were transferred to sterile water and the soil was saturated with this mixture and then allowed to dry thoroughly. This drying process required five hours. The spores require 8 to 9 hours to germinate; therefore none of the spores had time to form mycelium. The soil containing these spores was placed in an incubator at a temperature of 30° C. From time to time a bit of the soil was taken out and transferred to a plate of nutrient agar. The fungus was repeatedly re-isolated from the soil for a period of seven weeks, but it failed to grow at the end of that period.

The vitality of the mycelium was tested in the following experiment: Several samples of a sandy loam soil were sterilized and inoculated with the spores of F. annuum as previously outlined, but instead of allowing them to dry, they were kept moist for three days. This allowed the spores to germinate and to form mycelium. At the end of the third day the soil was dried and placed in an incubator at a temperature of 30° C. Cultures were made from these samples from time to time, and the fungus was re-isolated after ten months of desiccation.

Irrigation waters and methods of irrigation.—Chile peppers in New Mexico are grown under irrigation. The fields are either flooded or the water is allowed to run through furrows dug along-

side the plants. The importance of the running water as a disseminating agent should not be underestimated. Considerable quantities of dirt are washed away from one end of the field and are deposited along the route of the running water. Spores, bits of mycelium, and any pathogenic organisms which might be present in an infected part of the soil, will easily be carried along with the dirt and be distributed at quite a distance from their original source, establishing new centers of dissemination. A few days after the wilting of the diseased plants, large numbers of sporodochia appear on the underground stem, just below the surface of the soil. These can easily wash off in irrigation waters and their spores may be carried a great distance.

In order to demonstrate the ability of running water to carry spores present in the soil, the following experiment was conducted:- a glass tube four feet long and one inch in diameter was selected, both ends were plugged with sterile cotton, and it was heated red hot over a gas flame, allowed to cool, then it was filled three-fourths full with a sterilized sandy loam soil to which was added a solution prepared according to the following formula:

Ammonium nitrate	1 g.
Dihydrogen potassium phosphate	0.5 g.
Magnesium sulphate	0.25 g.
Cane sugar	5 g.
Water	100 c. c.

The tube was then placed in a slightly slanting position, and the dirt, by careful shaking, was distributed all along its entire length, thus leaving a space between the soil and the upper side of the tube. Spores of F. annuum were washed in a few c. c. of sterile water, and this was added to the soil about three inches inside of the upper opening of the tube. This solution was absorbed by the soil in an area of two inches, which was marked off. Then a gentle stream of sterile water was allowed to run from this end of the tube down to the opposite end until the entire soil was saturated. This process required less than two minutes. Thus the water ran over two inches of soil containing no spores, then over two inches of dirt to which water containing a large number of spores was added, and then over the rest of the soil in the four foot tube. After the soil was well wetted, the tube was plugged and laid aside. Two days later the mycelium appeared over an area of eighteen inches. Thus a gentle stream of water was found capable of carrying spores sixteen inches away from their original source. Under natural conditions dirt and spores may be carried

much further and cover large areas, since the irrigation water runs in furrows for a considerable length of time, varying from ten to fifteen minutes or more.

The best way to overcome this undesirable result of irrigation is to practice the ridging method of planting. The ridges should be made from eighteen to twenty-four inches high and four feet apart. Chile peppers which grow on top of these banks cannot come in direct contact with the running waters, and the moisture will go toward the roots by capillarity alone. The force of capillary movement of water in the soil is not strong enough to move the conidia of F. annuum through the spaces between the dirt particles. This was illustrated in the following experiment:—several Petri dishes were partially filled with a sandy loam soil to which the nutrient solution described in the preceding paragraph was added. The soil was then dried and sterilized in the autoclave. Spores of F. annuum were washed in sterile water and added, by means of a sterile pipette, to the center of the soil in the dishes. The water was applied drop by drop, allowing the soil to absorb each drop before adding another. This process was continued until most of the soil in the dishes was wet. That portion of the soil which was wetted by the direct contact of the water dropped from the pipette, was marked off from the soil wetted by capillarity; the remaining dry soil in the dishes was moistened by the application of sterile water. After two days the mycelium appeared as a white, dense, circular growth on the area which received the direct application of water containing spores; the rest of the soil remained sterile in every case. Similar results were obtained in another experiment:—several glass tubes, varying from two to twelve inches in length and having one-half inch diameter, were filled with a sandy loam soil; one end of the tubes was plugged with cotton and the other end covered with a layer of cheesecloth, and then they were sterilized in the autoclave. Spores of F. annuum were transferred to a number of beakers containing fifty c. c. of sterile water, and the tubes were placed in these beakers with the cheesecloth covered end in the water. After the water moved up the column by means of capillarity, samples of soil were taken from the upper ends of the tubes and plated. No growth was obtained in any of the cultures.

Descending or percolating waters, however, do carry spores with them. Several glass tubes four feet long and one inch in diameter were filled with a sandy loam soil, a few cubic centimeters of water containing spores was applied to the upper part of the

column, then distilled water was added until it passed through the entire column and began to drip out. When a drop of this was examined under the microscope, a number of typical F. annuum spores were observed.

Another advantage of the ridging method of planting and irrigation lies in the fact that the fungus will be prevented from spreading to the nearby rows through the roots of diseased plants. On the level ground the roots of the plants in the adjoining rows will always get tangled together, while the ridging method of planting confines them largely to the ridges. The fungus travels much faster in the plant tissues than it does in the soil. The greater part of the root system of a newly wilted plant is free from the fungus; within a week's time, however, the entire root system is invaded. This affords the fungus a very rapid means of spreading. For this reason large patches of infected areas appear within a short time around a diseased plant, when the level method of cultivation is practiced; but when the ridging method is used, rows of dead plants, instead of patches, appear in the field.

Direct growth of the fungus hyphae in the soil:—F. annuum has marked saprophytic properties and can grow readily in soils of ordinary fertility. The type or the structure of the soil has no influence upon the rate of the growth of this fungus. This fact was proven in the following experiment: very fine sand, sandy loam, loam, clay loam, and clay soils were selected and an equal amount of each was placed in Petri dishes. The nutrient solution, as described in the foregoing paragraph, was added to every sample, allowing the soil to saturate with it. The excess of water was removed by decantation and by the means of absorbent paper, then they were sterilized in the autoclave and inoculated with F. annuum. Ordinary field soil to which no nutrient solution was added was used as check. Fungus colonies appeared two days after the inoculation, and their diameters were measured from day to day as they grew, until the growth ceased; then five grams of soil was removed from every dish and the capillary moisture was determined. The rate of growth, which averaged a quarter of an inch a day at a temperature varying from 27°-30° C., remained constant in all of the different soil samples. The checks averaged a growth equal to that of the others, but the mycelium was thin and sparse, as compared with the dense and rich growth made on the soils to which nutrient solution was applied.

When the spores are disseminated by the irrigation waters and find suitable conditions, they soon germinate and attack the organic matter in the soil. By leading a saprophytic life the fungus

spreads in the layers of the soil. Its rate of growth, however, remains constant regardless of the amount of the organic matter. This was shown in the following experiment: A sandy soil was selected and placed in Petri dishes, filling them half full. These were divided into six groups; one group was used as check and received no organic matter,while the other groups received an application of 2, 4, 8, 10, and 15 per cent of organic matter, consisting of dried and powdered horse manure. The checks had only a trace of organic matter. These samples were sterilized in the autoclave and inoculated with F. annuum. The diameter of the ensuing fungus colonies was measured from day to day, and it was found that in all cases it averaged about a quarter of an inch a day at a temperature of 27°C.

Since ordinarily chile peppers are turned under after the harvest of the pods, the fungus will find sufficient food material for its growth and development. It may be argued that in the field where there are so many other soil organisms to compete with F. annuum will not be able to make as rapid a growth as it does under the laboratory conditions. The following experiment was conducted to see if other soil organisms exerted any hindering action upon the development of F. annuum: A number of Petri dishes were filled half full with a sandy soil. The nutrient solution was added to some of them, others received various applications of organic matter; fresh chile pepper roots were buried in the soil of a third group of dishes, and a fourth group was used as check. All the samples were saturated with water. These four groups of dishes were further divided into 2 subgroups; one was inoculated with F. annuum alone, while the other was inoculated with F. annuum, Rhizopus nigricans, an Aspergillus sp., a Penicillium sp., and an Alternaria sp. The spores from these different fungi were transferred to a small amount of water, and a drop of this water was used for inoculation. In all cases a mixed colony was the result. Except in the case where fresh chile pepper roots were used instead of nutrient solution or manure, Rhizopus nigricans outgrew all others, while F. annuum outgrew the Aspergillus, the Penicillium and the Alternaria species. Its rate of growth, however, remained constant, both in the mixed and in the pure cultures, averaging a quarter of an inch a day at a temperature of 27° C. In case of fresh chile pepper roots, F. annuum not only outgrew all others, but averaged a growth of more than one-half inch a day on ordinary roots, and about one inch a day on the rootlets.

In another experiment unsterilized field soil to which a little

nutrient solution was added, was inoculated with F. annuum and the ensuing growth watched from day to day. The other organisms present in the soil failed to exert any influence upon the normal rate of growth of F. annuum.

The direct growth of the fungus in the soil is largely dependent upon the amount of moisture present. It was seen that the type and structure of the soil had no direct influence upon the growth and the development of this organism. The moisture, therefore, remains as the chief controlling factor, but it, naturally, varies in different soils. The following table shows the relation of the fungus to the moisture content of different soils:—

Table III.—The Relation of F. Annuum to Moisture Content of Soils.

Type of Soil	Per cent soil moisture when growth of fungus stopped
Very fine sand	5.6 %
Fine sandy loam	7.3 %
Loam	8.5 %
Clay loam	9.2 %
Clay	10.5 %

It can be seen that the fungus requires a large amount of soil moisture to make an active growth. Ordinary green plants require much less, and can grow and function normally in soils the moisture content of which is not sufficient to induce a noticeable development of the fungus mycelium. This is perhaps why the wilt of chile peppers is invariably confined to wet soils.

Remains of diseased plants.—After the crop of chile pepper is harvested, the plants are allowed to remain where they grew until the time of plowing, when they are turned under. Naturally, there is much shifting of the plant remains, both diseased and healthy ones, so that the sources of inoculum are multiplied. It is of doubtful value to pull the plants out and destroy them, because when the plants are pulled, the diseased, weakened roots break off and remain in the soil. At the time of wilting only some of the roots are affected; if they are dug out and destroyed before the infection has time to spread to the entire root system, the results will prove more satisfactory. It is necessary to destroy all diseased plants. The fungus can keep its vitality under absolutely dry conditions for a long time. Spores from two-year-old cultures germinated very readily. These cultures were made on steamed chile pepper stems and kept in the laboratory; no rubber cap, sealing wax or paraffin was used to protect the cultures against drying. Some infected roots were kept in an incubator at an average temperature of 30° C. for nine months, and at the end of that period the fungus was isolated from them very readily. Others were dried at a temperature of 105° C. for seven hours, but the fungus was isolat-

ed from them repeatedly. On account of this remarkable vitality of the fungus the diseased plant remains constitute a very dangerous source of infection.

Cold frame infection of the seedlings.—While the writer has never observed any occurrence of wilt in the cold frames, it is entirely possible that after the soil is once infected, the fungus will be able to attack the seedlings which, upon being transplanted to the field before showing any symptoms, will serve as an excellent means of dissemination. Sterilization of the soil of the cold frames is a good practice and one that should be followed, in all cases.

Infection.—Infection generally takes place at the base of the underground stem or at the whorl of roots around it. When, during the transplanting operations, the seedlings are set too deep, any portion of the underground stem may become the seat of the infection, and the plants may wilt and die before many of the roots are attacked. No wound is necessary for the initial infection; the fungus penetrates the host through sound tissues, as inoculation experiments under controlled conditions have shown. The time between the initial infection and the eventual death of the host varies according to climatic and soil conditions and the resistance offered to the parasite. On an average, four or five weeks are sufficient to bring about a complete wilt of a full grown plant. Some succumb two weeks after the initial infection; others may resist for two or three months. After entering the host tissues the fungus develops readily and quite rapidly. If the initial infection is at the tip of the root, it gradually advances towards the stem and from there to the other roots, but in most cases before the entire root system is infected, the underground stem becomes so badly diseased that the plant dies. Then there follows an upward and a downward movement of the infection. The upward movement is very slow and restricted, especially when the fungus reaches the tissues of the plant above the ground. Nevertheless, it sometimes involves the lower part of the aerial stem. The downward movement, due to the large amount of moisture present in the tissues, is very rapid, so that within a week from the time of the wilting all the roots may become diseased.

Histological sections of the affected tissues show the fungus to be most abundant in the xylem and the phloem cells, but the hyphae can be seen in all tissues from pith to the bark or the cork cambium. Chlamydospores are often very abundant in the tissues of the cork cambium. No other types of spores have been observed.

Pathological physiology.—Wilting is not due to a mechanical plugging of the tracheal cells by the hyphae of F. annuum, nor to any toxic substance produced by the parasite. While the fungus hyphae are quite abundant in the conducting tissues of diseased plants, they do not occupy the vessels to such an extent as to stop the flow of the solutions. The fact that newly wilted plants are able to form new roots and foliage if given low enough temperature to check a rapid development of the parasite, is sufficient proof to show that toxic excretions play no part in the wilting of the chile peppers. This was further proven by the following experiment: the fungus was grown in Richard's solution at a temperature of 25° C. for four months. It made a very luxuriant growth and absorbed 1.15 per cent of the solids in the solution. At the end of four months the solution was filtered and chile pepper seedlings were transferred into the filtrate. Uninoculated Richard's solution and distilled water were used as checks. None of the seedlings showed any sign of wilting at the end of three days. A chemical analysis of the filtrate for the presence of alkaloids gave negative results.

The wilting is due to the breaking down of some of the invaded tissues, especially those of the cork cambium, the cambium, and the bark, and to the eventual girdling of the stem. This girdling has been closely followed in water cultures. The effect of the parasite upon the host, therefore, is a more or less rapid killing of the invaded cells rather than a complete clogging of the water conducting system.

ECOLOGY

Temperature.—Pepper plants thrive in warm climates and require a long growing season for their fruit to mature. The climatic conditions of New Mexico, especially those of the lower and warmer valleys, are well suited for the culture of chile peppers. The temperature is rather warm during the day, but it drops considerably at night. F. annuum requires not only a high, but a relatively constant temperature, as well, for its best development. The following table represents the average temperature of the soil of the Experiment Station farm for the years 1916 to 1918, inclusive. The temperature was taken three inches below the surface of the soil and recorded automatically:—

Table IV.—Average soil temperatures for the years 1916-1918.

	1916	1917	1918	Average
	°F	°F	°F	°F
January	58.4	44.4	46.5	49.8
February	53.4	50.2	47.6	50.3
March	61.6	53.6	61.2	58.8
April	63.7	60.6	68.4	64.2
May	68.3	65.3	70.2	67.9
June	75.1	76.9	77.2	76.4
July	77.0	84.0	76.6	79.2
August	75.3	80.3	76.3	77.3
September	70.8	79.2	77.0	75.7
October	64.2	71.8	64.7	66.9
November	55.6	64.4	49.8	56.6
December	53.4	53.2	43.2	49.6

The following table shows the air and the soil temperatures during the growing season of 1919:—

Table V.—Average soil and air temperatures for the growing season of 1919.

MONTH	Maximumsoil temperature	Minimum soil temperature	Maximum air temperature	Minimum air temperature
	°F	°F	° F	°F
April	63.4	50.3	75.4	44.7
May	68	55.5	84.3	50
June	78.5	64.1	91.2	58.8
July	87.3	75.8	91	66
August	86.7	75.5	92.9	64.5
September	74.3	67.9	82.5	59.2
October	68	59.9	74.2	48

June, July, August and September are the warmest months, as can be seen from the foregoing table. The first diseased plants appear during the latter part of June, but the largest number of infections take place in August. If there is a marked fluctuation of temperature, the disease may be expected to be checked somewhat. This point is illustrated in the following experiment: A number of water cultures were kept at a temperature of about 27°C. Two weeks after inoculation all plants, except checks, wilted. Another group of inoculated plants were kept in a room where the temperature was 20° C. during the daytime, and 15° C. at night. These plants wilted five to six weeks after inoculation. A third group was placed in an observatory where the temperature was 20°-22° during a part of the daytime, and 8°-10° at night. None of these plants wilted, and only the tips of the roots of some of them showed a brown discoloration. Newly wilted plants after being transferred to this observatory began to form new roots and foliage, but when taken back to the warmer room after making some growth, they wilted again.

Freezing does not seem to affect the vitality of the fungus. Nutrient agar cultures were frozen at a temperature of 12° F. overnight, and the next day when spores from these were transferred to hanging drop cultures, they germinated very readily within 8 to 10 hours.

Soil.—So far as the direct influence of the soil is concerned, F. annuum is not at all affected, as was shown by the fact that it grew equally well on all types of soils, other conditions being similar. The indirect influence of the soils, however, is of much importance, especially from the standpoint of their water holding capacity. The temperature differences of different types of soils are not so important as some think them to be. Haskell (4) believes that the relation of the soil type to the Fusarium wilt of potatoes is principally due to the difference in temperature, and that clay soils having a greater water holding capacity are cooler than sandy soils, the moisture content of which is much less. Bouyoucos (5) has shown that this difference is comparatively small, as can be seen from his figures, some of which are given in the following table:—

Table VI.—Seasonal and Yearly Average Temperatures of Different Types of Soil.

1914-15 Season	Sand Depth 4 in.	Loam Depth 4 in.	Clay Depth 4 in.
Winter			
Dec.	31.81°F.	33.56°F.	32.96°F.
Jan.	31.28 "	32.05 "	32.03 "
Feb.	32.73 "	32.13 "	32.31 "
Average	31.94 "	32.58 "	32.43 "
Spring			
Mar.	34.48°F	33.89°F	32.96°F
Apr.	54.36 "	52.95 "	32.03 "
May	58.11 "	56.37 "	32.31 "
Average	48.88 "	47.74 "	47.03 "
Summer			
June	68.55°F	66.42°F	65.46°F
Jul.	74.96 "	72.82 "	71.55 "
Aug.	70.00 "	68.06 "	68.17 "
Average	71.17 "	69.10 "	68.39 "
Autumn			
Sep.	67.41°F	65.90°F	65.47°F
Oct.	53.97 "	52.78 "	52.34 "
Nov.	41.52 "	41.45 "	41.18 "
Average	54.30 "	52.38 "	53.00 "
Yearly Average	51.60°F	50.70°F	50.21°F

The temperature of different soils taken at a depth of 12 or 18 inches shows the same relationship as that given in the above table. Therefore it is safe to conclude that this difference of temperature exhibited by different types of soils is not important enough to affect the chile wilt organism. Most of the wilt occurs during the middle of August and September, yet these months are, on the average, from 2 to 4 degrees cooler than July. The temperature, beyond a certain point (23°-25° C.), ceases to be a controlling factor in the development of this disease.

Moisture.—The greatest single controlling factor in the occurrence and the severity of this disease is the soil moisture. It has been a matter of common observation that the wilt of chile pepper is most serious in low, wet fields, on crop growing in heavy or clay

soils, and on undrained land. Chile pepper fields in the low and wet lands have suffered the most, while those situated on the uplands where there is natural drainage, have remained comparatively free from infection. The following extract from the letter of a farmer is very typical: "...the people on the river have almost gone out of the business of trying to raise chile. The trouble seems to be in the water of the Rio Grande River. I am back three miles from the river, and I have no trouble at all in growing the crop. People in the mountains grow it without difficulty." Low lands lying alongside the river do not as a rule have as good drainage as those on the uplands, and the wetter a soil is, the more susceptible will the crop be to the disease.

Heavy rains and general outbreaks of Fusarium wilt of chile peppers seem to go hand in hand. The records show that the wilt was very destructive in 1912, and that most of the damage was done in August. An unusually large amount of rainfall is recorded for that month, as can be seen from the following table:

Table VII.—Daily Rainfall in August, 1912.

August	2	0.13 inches
"	4	0.20 "
"	12	0.35 "
"	13	0.10 "
"	15	0.69 "
"	16	0.03 "
"	18	0.73 "
"	19	0.06 "
"	20	0.15 "
"	23	0.13 "
"	24	1.14 "
"	27	0.98 "
"	29	0.10 "
"	31	0.43 "
Total		5.04 "

July and August are rainy months. The humidity of the air and the moisture content of the soil are usually higher during these months than at other times. The fungus activities in the soil, due to these favorable conditions, accelerate in July, and manifest themselves in August.

Most of the irrigated fields have "low spots" or "wet pockets" where the moisture accumulates and cannot be drained off without some artificial means. When fields are leveled for irrigation, the land is given a more or less gentle slope; the lower part of this slope receives more water and loses less moisture by drainage than the upper parts. Chile plants growing in these low spots become heavily infected, and very often the entire crop in these sections becomes a total loss. This fact is corroborated by numerous observations and statements by farmers, county agents and members

of the Extension Division and Experiment Station staff of this College.

In co-operation with the Horticultural Division of this Station, four acres was planted to chile pepper and kept under close observation during the growing season of 1919. The cultural work of these plots was done under the direction of Prof. F. Garcia. Plot 1 was situated just at the border of the mesa; the soil was sandy, and the natural drainage excellent. Plot 2 was in a low field with a marked slope towards a public road. Plot 3 was in a cherry orchard and the plants were shaded by the foliage of the trees. Plots 4, 5, and 6 were in a field which, prior to the 1919 crop of chile peppers, was occupied by nothing but old peach trees. The first wilted plants were observed in the lower part of Plot 2 during the latter part of July. The infection began to spread rapidly in the wet pocket until in about two weeks nearly twenty per cent of the plants died. After that only an occasional plant wilted. The upper, drier part of the field showed less than two per cent infection. This field had been planted to chile peppers the previous year, and 50 to 60 per cent of the plants in the low and wet part of the plot were killed. It was only logical to expect a more serious infection during the growing season of 1919; but contrary to all expectations the number of the diseased plants fell to twenty per cent. The moisture content of the soil averaged 17 per cent; the moisture, therefore, was not the only controlling factor in this case. The writer can advance only one theory to explain this: nematode-infected plants seem to show a marked resistance to the Fusarium wilt. The great majority of plants in this plot were seriously affected by nematodes during the summer of 1919. In other plots, where nematode activities were not as noticeable, it was repeatedly observed that in areas infested with the wilt, nematode-infected plants were, in most cases, the only ones not killed by the wilt organism. This point is well illustrated in table 9, where most of the surviving plants in a wilt infested area are shown to be affected with nematodes. The heavier the nematode infection is, the more resistance the plants seem to show to the wilt. Chile plants suffering from nematodes remain stunted if attacked early in the season, branch sparingly or not at all, the leaves turn yellow, become wrinkled and brittle, and the rootlets do not grow, but remain as short, club-like stubs.

When the nematode infection in Plot 2 reached its maximum development in August, the Fusarium wilt stopped almost altogether; while in the other plots where nematodes were not serious, the wilt became most active in August and September.

The most serious outbreak of wilt occurred in Plot 5. Here the lower part of the field represented a low, wet pocket where 85 per cent of the plants were killed, while only two per cent of the plants growing in the upper part, not more than fifty feet away, wilted. Nearly four hundred soil samples were taken from these two parts of the Plot 5, and the capillary moisture content of the soil was determined. A fourteen-inch soil tube was used to take the samples. The figures given in the following tables represent the moisture of the upper foot of soil of the field:—

Table VIII.—Average Soil Moisture of Plot 5.

Upper Field	Per cent plants killed. .2	Lower Field	Per cent plants killed. .85
Minimum per cent soil moisture	Maximum per cent soil moisture	Minimum per cent soil moisture	Maximum per cent soil moisture
6.49	12.11	13.97	19.62

The minimum percentage of soil moisture represents the capillary water of the soil just before irrigation, while the maximum percentage of moisture refers to the capillary water of the soil one day after irrigation. It can be seen from the above table that the moisture content of the lower part of the plot is almost twice as much as that of the upper field, and the difference between the percentages of the diseased plants of the upper and the lower parts of the same plot is too obvious to require comment.

Three representative rows were selected from Plot No. 5 and soil samples for moisture determination were taken from the base of every fifth plant. The condition of the plant, whether healthy or wilted, was recorded. The samples were taken one week after irrigation. The table on the following page gives the results of these tests.

This table shows that the amount of soil moisture and the condition of the plants correlate quite constantly. A high moisture content runs parallel with a high percentage of diseased plants. A few infected plants may be found where the moisture content of the soil is low, just as there may be some plants growing in wet spots, and apparently not affected with the disease. This may be due to a low or high resistance in the plants to the disease, and to the absence or the presence of the fungus in the soil. The general average, however, is so striking in its effect that the role of soil moisture in the occurrence and the severity of the disease cannot be doubted. An examination of the following table will illustrate this point still further. Soil samples were taken from the base of every plant of a representative row in Plot 5, and the capillary moisture was determined. Each plant is described as dead, healthy,

Table IX.—Relation of Soil Moisture to Wilt of Chile.

ROW 1			ROW 2			ROW 3		
No.	Per cent of moisture	Condition	No.	Per cent of moisture	Condition	No.	Per cent of moisture	Condition
1	8.6	Healthy	1	8.6	Healthy	1	7.5	Healthy
2	9.8	Dead	2	12.1	"	2	9.8	"
3	11.1	"	3	9.8	"	3	11.1	"
4	13.6	"	4	11.1	"	4	12.3	"
5	12.3	"	5	12.1	Dead	5	14.9	Dead
6	14.9	"	6	13.6	"	6	19.0	"
7	17.6	"	7	9.8	Healthy	7	17.6	"
8	17.6	"	8	18.0	Dead	8	17.5	"
9	17.6	"	9	14.9	"	9	19.0	"
10	12.2	Healthy	10	16.2	"	10	17.6	Healthy
11	17.6	Dead	11	13.1	"	11	20.4	"
12	17.6	"	12	11.1	Healthy	12	19.0	"
13	19.0	"	13	13.1	Dead	13	13.6	"
14	16.0	"	14	12.1	Healthy	14	16.2	Dead
15	13.6	Healthy	15	11.1	"	15	12.3	Healthy
16	16.3	"	16	9.8	"	16	12.3	"
17	16.2	Dead	17	14.9	Dead	17	11.1	"
18	17.6	"	18	11.1	Healthy	18	13.6	"
19	13.6	Healthy	19	12.1	Dead	19	11.1	Dead
20	12.3	"	20	11.1	Healthy	20	12.3	Healthy
21	11.1	"	21	11.1	"	21	11.1	"
22	11.1	"	22	9.8	"	22	11.1	"
23	12.3	"	23	9.8	"	23	9.8	"
24	11.1	"	24	6.3	"	24	8.6	"
25	9.8	"	25	7.5	"	25	8.6	"

or affected with nematodes. Mild nematode infections have been described as healthy, since a slight attack of these worms does not seem to render the plant resistant to the wilt.

Table X.—The Relation of Soil Moisture and Nematodes to the Wilt of Chile.

No	Per cent moist.	Condition	No	Per cent moist.	Condition	No	Per cent moist.	Condition	No	Per cent moist.	Condition
1	9.8	*D	33	17.5	D	65	16.0	†N	97	11.1	§H
2	9.4	H	34	19.0	D	66	13.6	N	98	12.3	N
3	9.8	H	35	17.6	D	67	12.3	D	99	9.8	H
4	9.4	D	36	14.9	N	68	12.3	"	100	12.1	"
5	12.3	"	37	22.0	D	69	13.6	"	101	9.8	"
6	14.9	"	38	22.0	D	70	13.6	"	102	12.3	"
7	14.9	"	39	17.6	N	71	16.2	"	103	11.1	"
8	13.6	"	40	19.0	D	72	13.6	H	104	9.8	N
9	12.3	"	41	17.6	D	73	11.1	"	105	12.3	N
10	14.9	"	42	20.4	N	74	13.6	"	106	8.6	H
11	14.9	"	43	20.4	D	75	12.3	"	107	9.8	"
12	16.2	"	44	16.2	N	76	12.3	"	108	9.8	"
13	14.9	"	45	16.2	D	77	12.3	"	109	8.6	"
14	16.3	"	46	16.2	D	78	13.6	"	110	8.6	"
15	16.2	"	47	13.6	H	79	14.9	N	111	9.8	"
16	16.2	"	48	16.2	D	80	12.3	D	112	9.8	N
17	16.0	"	49	14.9	D	81	12.3	H	113	7.5	H
18	13.6	"	50	14.9	D	82	12.3	"	114	8.6	H
19	19.0	N	51	17.6	H	83	12.3	"	115	9.8	H
20	17.6	D	52	16.2	"	84	8.6	"	116	8.6	H
21	16.2	D	53	16.2	"	85	12.3	"	117	7.5	H
22	14.9	H	54	16.2	D	86	12.3	"	118	7.5	H
23	14.9	D	55	13.6	D	87	9.8	"	119	7.5	"
24	13.6	"	56	12.3	H	88	9.8	"	120	9.8	"
25	17.6	"	57	13.6	H	89	9.8	N	121	8.6	"
26	19.0	N	58	16.2	D	90	9.8	N	122	7.5	"
27	19.0	D	59	16.2	D	91	11.1	H	123	9.8	"
28	17.6	"	60	13.6	H	92	9.8	"	124	8.6	"
29	19.0	"	61	16.0	D	93	11.1	"	125	8.2	N
30	16.2	"	62	16.2	"	94	9.8	"	126	11.1	H
31	17.6	"	63	17.6	"	95	11.1	"	127	9.8	"
32	16.2	"	64	16.2	"	96	12.3	"	128	8.6	"

*Dead †Nematode §Healthy

In order to determine if there were other secondary causes affecting the host or the parasite, chemical and physical analyses of soil samples, both from the upper and the lower parts of Plot 5 were made. The results are tabulated in tables 11 and 12.

Table XI.—Chemical Analyses of Soils from Plot 5.

Sample No.	Per cent of total solids	Per cent CaO	Per cent CO2	Per cent Cl	Per cent SO3
			Upper Field		
1	.256	.045	.011	.046	.057
2	.1[illegible]2	.034	.011	.036	.046
3	.140	.034	.011	.023	.037
4	.162	.045	.015	.033	.056
5	.208	.045	.011	.033	.054
			Lower Field		
1	.114	.028	.015	.0[illegible]2	.027
2	.1[illegible]4	.028	.015	.023	.028
3	.168	.034	.015	.012	.029
4	.268	.034	.015	.035	.062
5	.170	.034	.020	.012	.047

This table shows that the difference between the upper and the lower soil is not large enough to have any appreciable effect upon the plants or the parasite, and that both soils are normal for New Mexico.

Table XII.—Physical Analysis of the soil from Plot 5.

Field	Per cent of sand	Per cent of silt	Per cent of clay
Upper	87.4	6.2	6.4
Lower	72.7	16.3	11.1

The soil of the upper field is, according to this analysis, sandy; while that of the lower part of the field is sandy loam. This will tend, naturally, to increase the water holding capacity of the soil, but the most important cause for the high moisture content of these low spots is to be attributed to the lack of drainage, rather than to the structure and texture of the soil.

Plants growing in Plot 1 remained free from the disease throughout the season. As stated before, this plot was situated just at the edge of the mesa and had good drainage. The maximum capillary moisture of this soil was about 12 per cent, and the minimum 4 per cent; this gives an average of 8 per cent, which is too low to promote the disease. It is true that no chile or any other crop was ever grown on this soil, but on the other hand, Plots 4, 5, and 6 were occupied, prior to their being planted to chile peppers, by nothing but peach trees. Therefore, a heavy outbreak in Plots 5 and 6, and no disease at all in Plot 1, cannot be explained by the theory of the presence and the absence of the organism causing it, but by the amount of moisture present in the soil. The upper part of Plot 5 was almost free from the disease, while the lower part of the same plot, only a short distance away, contained almost nothing else but

diseased plants. Plot 6 had a low, wet area in the middle. Almost all of the plants in this area were killed, forming a sharp contrast to the healthy plants bordering them and growing on higher ground. Similar cases have been observed in almost every chile field visited by the writer. Inoculation experiments in the field show the same results. Only five per cent of the inoculated plants in the upper part of Plot 4 wilted, as against 65 per cent of positive inoculations in the lower and wetter part of the same plot. This was demonstrated still further in the laboratory and under controlled conditions. A sandy soil was selected and divided into six lots. The first lot received no application of organic matter. Well powdered and dried horse manure was added to the other lots at the rate of 1, 2, 4, 8, and 10 per cent. These soil samples were placed in a number of test tubes which were divided into two groups. The soil in one group was kept saturated with water throughout the experiment, while the other was kept just wet enough to prevent the plants from wilting. Chile seedlings grown in sterile sand were transferred to these test tubes and inoculated with F. annuum by applying equal amounts of spore dilutions to each tube. Every third plant was used as check. Within three weeks all the plants growing in the wet soil wilted, while the checks, and those in the inoculated but drier soil, remained unaffected. If the soil is kept constantly wet, the amount of organic matter present does not have any effect upon the disease, as it was seen that plants growing in soils to which no organic matter was added wilted just as readily as did those planted in soils containing from one to ten per cent of organic matter. When no effort is made to keep the soil constantly wet after the first saturation, soils with higher organic matter will contain more moisture and retain it much longer than those with little or no organic matter. In laboratory experiments it was seen that seedlings growing in soils having no organic matter were the last to wilt.

SUMMARY AND CONCLUSIONS

A serious wilt of chile peppers, which since 1911 has been very destructive in New Mexico, is caused by a new species of Fusarium (section Martiella), for which the name F. annuum is proposed.

The symptoms of the disease are a sudden wilting of the foliage, a total destruction of root hairs, the browning of the roots and the breaking down of their cork cambium, the disintegration of the bark cells and the cambium of the underground stems, the smoky discoloration of the wood, the production of white or

bluish sporodochia on some of the underground stems, and the appearance of dark brown, sunken lesions on the underground stem and often on the base of the aerial stem.

The soil is the chief source of inoculum. Dust storms, irrigation waters, the direct growth of the fungus mycelium in the soil, diseased plant remains, and possibly infected seed beds are the principal sources of dissemination.

The wilting of the diseased plants is not due to a mechanical stoppage of the water conducting tissues by the hyphae of the parasite. The fungus does not produce any toxic substances which may affect the host. A general breaking down and disintegration of the invaded tissues is the cause of the wilt.

The soil temperature is closely related to the occurrence of the disease up to a certain degree. The heaviest outbreaks of the wilt occur in August and September.

The optimum temperature for the fungus is around 31° C., but the highest average soil temperature in the field is 25° C. The soil temperature is from 2 to 4 degrees higher in July than it is in August and September, yet most of the infection takes place in August and September. On the other hand, when the average soil temperature is much below 17° C., no infection is possible.

The soil moisture is the chief controlling factor. It was found that when the average capillary moisture was below 12 per cent, only 2 per cent of the plants wilted; but when it was much higher than 12 per cent, 85 per cent of the plants wilted. Five per cent of the inoculated plants in the drier soils wilted, as against 65 per cent of the positive inoculation in the wet soils. Laboratory experiments under controlled conditions gave similar results.

Since there is such a close correlation between high moisture content of the soil and the Fusarium wilt of chile peppers, it follows that anything which will check the soil moisture will also check the disease. In the first place, heavy soils should be avoided and light soils given preference. If the natural drainage of the soil is poor, artificial drainage will prove to be a good investment, as it will not only control the wilt, but will also improve the physical and the chemical condition of the soil. Too much emphasis cannot be placed upon an intelligent practice of irrigation. Irrgation should not follow a definite schedule, but the land should be watered only when the minimum amount of soil moisture falls below the actual needs of the plant.

Digging diseased plants and destroying them, sterilizing

seed beds, growing plants on high ridges instead of on level ground, and protecting the fields against the prevailing winds by the means of windbreaks are sanitary measures which will not fail to yield good results.

Crop rotation is of doubtful value, since even the virgin soils have been found to abound with disease producing organisms; nevertheless it is not a wise thing to overlook the fact that a certain degree of protection always exists with crop rotation, even under the unfavorable climatic conditions of New Mexico.

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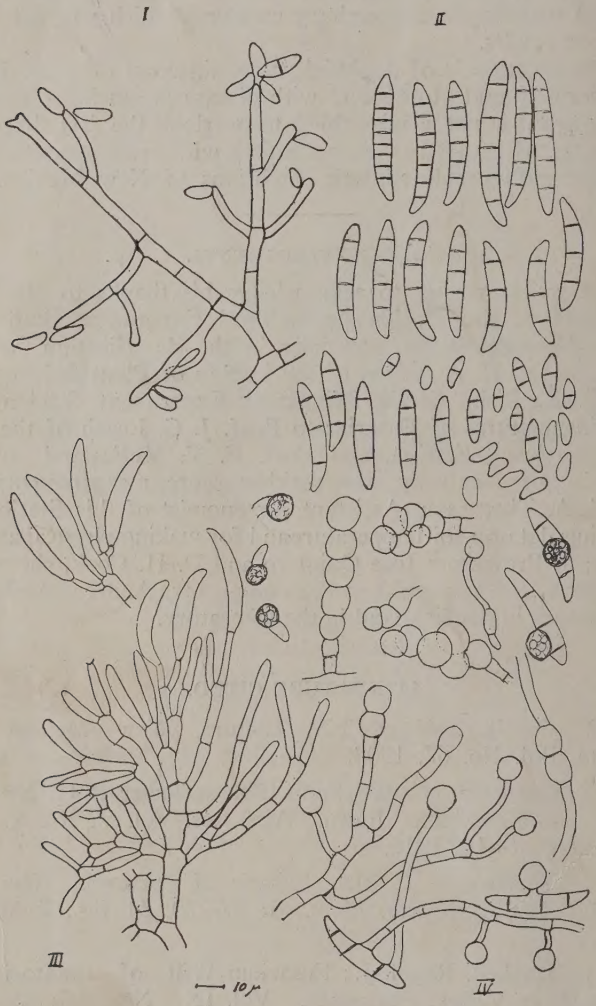

Fig. 7.—Fusarium annuum n. sp. (Drawn with the aid of camera lucida.)

I. Microconidiophore with conidia.
II. Conidia of various types.
III. Macroconidiophore with conidia.
IV. Chlamydospores and various methods of chlamydospore production.